# THE USE OF WETLANDS FOR STORMWATER STORAGE AND NONPOINT POLLUTION CONTROL: A REVIEW OF THE LITERATURE

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## ABSTRACT

**The Use of Wetlands for Stormwater Storage and Nonpoint Pollution Control: A Review of the Literature.** Resource Planning Section, King County Department of Planning and Community Development, Seattle, WA., July 1, 1986. Washington State Department of Ecology, WDOE Project Number G0086039, 20 pages.

There is a limited amount of information in the literature regarding the long-term effects of using freshwater wetlands for stormwater storage and nonpoint pollution control. Much of the related literature pertains to the use of wetlands for sewage effluent treatment. Some work has been done in other parts of the country utilizing natural or artificial wetlands for flood control and/or water quality management. Water quality improvements from these studies show promise, but their direct application to this region is limited. Some researchers believe the characteristics of wastewater and urban runoff are similar enough that findings in the wastewater literature may be analogous to stormwater systems. These findings can be confirmed by careful studies in the Northwest to help fill the gaps in present knowledge.

It is well established in the literature that wetlands improve water quality. The long-term consequences of storing urban stormwater in wetlands is uncertain and is an area of needed research. Information is needed before rational management and policy decisions can be made. Few stormwater and wastewater treatment studies have operated long enough to examine the long-term impacts to wetlands.

This paper summarizes wetlands water quality improvement principles from the literature, and areas of greatest uncertainty regarding the use of wetlands for urban stormwater management.

The annotated bibliography compiled as part of this study is contained in a document titled **Viability of Freshwater Wetlands for Urban Surface Water Management and Nonpoint Pollution Control: An Annotated Bibliography.** Resource Planning Section, King County Department of Planning and Community Development, 1986. 234 citations, 106pp. Seattle, WA.

# THE USE OF WETLANDS FOR STORMWATER STORAGE AND NONPOINT POLLUTION CONTROL: A REVIEW OF THE LITERATURE

## I. INTRODUCTION

Interest has developed in the Northwest in using freshwater wetlands to store stormwater and absorb nonpoint pollution. While surface water managers and developers would like to use natural drainage systems to route and store urban stormwater, resource managers are concerned about the long-term consequences of such actions on wetlands.

In 1986 the Resource Planning Section of King County Washington began a study to determine the feasibility of using freshwater wetlands to manage urban runoff and control nonpoint pollution. An annotated bibliography was compiled and reviewed to determine what information from the literature was available that could help answer questions on the long-term impact of urban stormwater on wetlands and, conversely, the effect of wetlands on urban stormwater. A review of that literature has yielded considerable information, but its applicability to Northwest wetlands is uncertain. Much of the related literature pertains to the use of wetlands for wastewater(1) treatment. Wetlands in the Pacific Northwest have not received substantial study as compared to wetlands in other areas of the country. This is not surprising, considering that the Pacific Coastal Region(2) wetlands comprise a mere 1.7 percent of the national total (Nixon and Lee 1985). The bulk of the research conducted in the country has centered on wetlands of the East Coast and in the Midwest. Of the research conducted in the Pacific Northwest, most of it has focused on estuarine rather than freshwater systems.

**Research over the past two decades has documented that wetlands provide a broad spectrum of ecological functions and values.**

These include the provision of wildlife habitat, improvement of water quality, recharge of groundwater, control of flood water, food chain support, as well as recreational, aesthetic and cultural values. This multiplicity of roles has led to a growing recognition that remaining wetlands should be retained as viable ecological systems.

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1 For the purposes of this paper, wastewater refers to sewage effluent. Stormwater can conceivably be considered wastewater, but here refers to urban runoff from impervious surfaces.

2 The Pacific Coastal Region is roughly defined by the Army Corps as most of Washington, more than half of Oregon, and coastal California.

Research on the potential use of wetland plants and soils for water purification began in 1953 with the work of Kathe Seidel in West Germany (Seidel 1976). Seidel assessed the ability of aquatic macrophytes to remove pollutants from water, and discovered that certain species of bulrushes, rushes and reeds work well. During the mid 1970's, interest in the use of wetlands for wastewater treatment grew out of a search for alternatives to traditionally expensive, and energy intensive, advanced sewage treatment facilities. This alternative seems particularly promising for small communities that require advanced (tertiary) treatment for the removal of nutrients in wastewater. Interest has also increased in recycling secondary-treated wastewater discharge as a source of freshwater for restored and altered wetlands. A considerable body of literature on these subjects has developed but it is considered to be limited in its direct application to the Northwest for urban runoff treatment problems. This is due to the Northwest's unique hydrologic and climatic regime as well as the indigenous wetland vegetation types. Nevertheless, some researchers believe the existing body of literature indicates wetlands may provide an alternative treatment for urban runoff under certain circumstances (Chan et al.1981, Silverman 1983). Horner (1986) notes that regional differences can be taken into account and conclusions from research in other regions can be confirmed by careful studies in the Northwest. While the use of wetlands for storage of urban runoff and treatment of nonpoint pollution associated with urban runoff holds tremendous promise, there is need for research on the long-term wetland effects.

By their hydrologic nature, many wetlands receive surface runoff, and therefore planned or unplanned urban runoff, from adjacent land. Traditionally, urban stormwater management has concentrated on rate control. Quality control of urban runoff is a relatively new consideration.

Based on a review of applicable literature, a summary follows of what we know and what we do not know about the use of wetlands for storing urban runoff and controlling nonpoint pollution.

## II. <u>WHAT WE DO KNOW</u>

**It is well established in the literature that wetlands improve water quality.** (Chan et al.1981, Horner 1986, Kadlec 1978, Hickok 1977/1980, Sloey et al. 1978)

A combination of physical, chemical and biological mechanisms act to remove pollutants from water in a wetland. These mechanisms are complex, are interactive, and are difficult to assess individually. Pollutants are either lost to the atmosphere by evaporation, are incorporated into sediments, are taken up by biota, are degraded, or exit the wetland in the runoff stream.

The initial pollutant removal mechanisms in wetlands are physical and chemical processes, followed by biological processes. Each of the major processes are described below, although they do not necessarily occur in all wetlands. It is not the purpose of this paper to discuss these processes in detail, but rather to provide a brief synopsis.

Sedimentation is one of the principal mechanisms of pollutant removal in wetlands. Retention of suspended solids in wetlands is directly related to flow characteristics in the particular wetland (Brown 1985). Wetlands with minimal defined channels and greater sheet flow are most effective (Morris et al.1981). Hydraulic resistance with the vegetation and soil decreases the velocity of water entering a wetland and enhances the settling/deposition of suspended sediments (Boto 1979). Since a majority of heavy metals, as well as BOD, nutrients, refractory organics, hydrocarbons, bacteria and viruses are adsorbed onto particulates, they too are effecively deposited with the trapped sediment (Chan et al. 1981,Silverman 1983). Both particulates and their associated pollutants may be considered pollutants. High loads of sediments in streams can scour and abrade stream channels, cause silting, reduce light, cover fish spawning beds, and bury benthic organisms. The rate of sedimentation in a wetland is directly related to the size of the particulate, the hydrologic regime, configuration of channel flow, flow velocity, and storm surges (Brown 1985). Soil characteristics and plant types within a wetland also affect sedimentation. As the percentage of clay in the soil decreases, the sedimentation rate in the wetland increases (Brown 1985). Toxicants are generally found to be associated with the smaller-sized particulates, generally those smaller than 246 microns (Oberts 1977). Thus, the control of sedimentation of small particles is a major factor in the control of urban stormwater nonpoint pollution.

Adsorption is a physical and chemical process by which dissolved pollutants adhere to suspended particulates or on to bottom sediments and vegetation surfaces. It is enhanced by extended contact with porous sediments through which water percolates. Adsorption is dependent on the sediment type, surface area, and percent of free ions in the sediment. Adsorption is also the primary virus removal mode for water percolating through soils (Silverman 1983). Richardson (1985) found that the phosphorus adsorption capacity of a wetland soil can be predicted by measuring the extractable aluminum content of the soil.

Filtration occurs as particulates are mechanically filtered through sediments, vegetation and biota (mussels, etc). Densely vegetated wetlands offer substantial filtration area. Removal of pollutants by filtration through a layer of soil is a complex process, and is effective in removing BOD causing organic matter, phosphorus, bacteria, and suspended material. This process is dependent on the specific characteristics of soils in the basin (Smith 1982). Filtration is the primary bacterial removal mode when water percolates through soils (Silverman 1983).

Soils of unconsolidated silty sands and gravels of glacial origin, such as is common in certain areas of the Pacific Northwest, provide ineffective removal of viruses from secondary-treated wastewater that passes through it (Silverman 1983).

Both adsorption and filtration removal mechanisms depend on the presence of soil types which allow percolation and infiltration. High clay content soil can effectively prevent water from percolating through the soil horizon. Soils on the west coast are often high in clay. Low soil permeability of certain soils in the Puget Sound region can inhibit the effective use of retention basins for stormwater management. Detention and settling basins can be used without percolation, by reducing flow rates. Given the high variability of geologic substrates in the Pacific Northwest, there would be a parallel variability in the ability of soils to filter or to form impervious barriers to stormwater.

Biological Assimilation: Wetland vegetation offers high pollutant adsorption and absorption (biological uptake) potential, as well as providing a substrate for microbial activity. The rate and specificity of pollutant uptake varies between each plant species. Nutrients, heavy metals and other compounds vary in their relative availability for uptake and decay depending on pH and other conditions. Much of the information in the literature concerning the uptake of nutrients and pollutants by vegetation was developed in wastewater research and has been summarized in The Environmental Requirements of Aquatic Plants (Stephenson et al. 1980). When plants take up pollutants through their roots, exchange sites in the sediments are freed for further pollutant adsorption by the soil. Plants can also absorb some nutrients and ionic compounds from the water via shoots and leaves. Nutrients, heavy metals and other substances that are taken up can be released to the environment when the vegetation dies or discards tissue.

Dissolved phosphorus is generally taken up by the vegetation during the growing season and released, to some extent, in the fall, depending on hydrologic and environmental conditions (Brown 1985).

Microbial Decomposition occurs both aerobically and anaerobically in the water column, on substrate surface and within the soil. BOD removal in wetlands is carried out by decomposing microorganisms. Denitrification is cited as a major process for nitrogen removal from wetlands (Lee 1975). Wetland sediments are commonly anaerobic, a necessary condition for denitrifying bacteria. Heavy metals are converted to relatively insoluble sulfides in reduced soils which are characteristic of anaerobic conditions (Chan et al. 1981).

Chemical Decomposition, such as photochemical reactions and chemical oxidation and reduction, may occur in addition to the mechanisms listed above.

The use of wetlands for wastewater treatment is well documented in the literature (Heliotis 1982, Chan 1981, EPA 1985).

A number of natural wetland types have been studied for wastewater treatment potential. These include northern wooded swamps, cattail marshes, southern cypress swamps, freshwater tidal marshes, salt marshes, and others. Most of the data in the literature relates to nutrient inputs and outputs and to production and nutrient assimilation by plants. Little is known about the rates of transport to or assimilative capacities of the different wetland compartments (Sloey et al. 1978). Reed (1979) summarized that wastewater treatment wetlands can reduce BOD in the discharged water by 50-90 percent of the inflow water, suspended solids by 60-90 percent, nitrogen by 30-98 percent and phosphorus by 10-90 percent. The variance in these removal rates are due to differences in wetland type, vegetation type, loading rate and climate differences (such as availability of solar radiation and temperature), all of which make direct comparisons between the wetlands difficult. Artificial or constructed wetlands have also been used because they can be planned specifically for wastewater treatment and therefore are subject to more control. The same principle would likely hold for treatment of stormwater. Results from the literature indicate that at least in the short-term, wetlands do improve water quality; however, the long-term ecological effects on wetlands is uncertain. Sloey et al. (1978) state it is almost certain that long-term application of some wastewaters to wetlands will result in cases of nutrient toxicity, heavy metal accumulations or even public health problems. Some wastewater treatment applications to wetlands have led to severe ecological disruptions (EPA 1985). Brennan (1985) noted that "Research at wetland treatment sites in the midwest and in Florida has indicated that the introduction of wastewater may cause permanent changes in the components of wetland communities and thus result in the simplification of these ecosystems and the elimination of some of their characteristic species, functions and values. The long-term effects of the discharge of treated wastewater at current study sites will not be evident for many years."

Stephenson et al. (1980) compiled an extensive summary report on the environmental requirements of wetland plant species with high potential for treatment of wastewater. The report discusses the effects of physical and chemical parameters and uptake of specific substances. It is a wealth of information for selecting emergent, floating and submerged plant species for water pollution control. This report is part of an overall assessment of the use of plants and animals for wastewater treatment.

The US Enviromental Protection Agency (1984) compiled an annotated bibliography on the ecological impacts of wastewater on wetlands to help develop appropriate treatment techniques based on an understanding of wetland ecology. The authors of this bibliography concluded that little research on the ecological aspects of wastewater addition to wetlands has been undertaken to date, especially on the long-term effects.

At least two regions in the Northwest, the City of Cannon Beach, Oregon, and the City of Black Diamond, Washington, have begun using wetland systems for wastewater treatment. Cannon Beach has designed an aerated/facultative lagoon and marsh treatment system for use during the summer when natural flows to the marsh decrease and summer wastewater volume increase. The system has met treatment standards since it began service in June 1984 (Thompson 1985). Black Diamond has been using an aerated lagoon and peat bog system since 1983. It has been declared a failure, however, and its peat soils have reached a saturation point for phosphorus adsorption (R.W. Beck & Assoc. 1985).

**Information on water quality improvements of stormwater passing through wetlands is limited, but shows strong promise.**

Several projects which have utilized natural or artificial wetlands for flood control and/or water quality management have been reported in the literature. These projects have shown consistent BOD, suspended sediment and heavy metal reductions in the discharged water. Nutrient removal rates vary widely between each project. The ability of a wetland to improve water quality of influent stormwater varies considerably between sites because of differences in hydrologic regime, water chemistry, vegetation, basin hydrology, soil type, season, and geographic location. The following is a brief summary of eight studies reported in the literature:

1. Northern peatlands, Wayzata, Minnesota: Hickok et al. (1977/80) studied a 7 acre peat wetland adjacent to a lake, which consisted of mixed grasses, cattails, willows, and dogwood. Studies indicated that stormwater from Wayzata, MN. was the major pollutant source to the lake and interest developed in evaluating the use of the wetland for water purification. Results indicated that the wetland retained 77 percent of the phosphorus entering the wetland, and 94 percent of total suspended solids. This retention was attributed to physical entrapment by organic soils and subsequent microbial degradation. An environmental assessment concluded that no impacts could be detected on the wildlife or vegetation as a result of the project. The length of time of project operation was not reported. The wetland was found to be a groundwater discharge zone.

2. Cypress wetlands, Orlando, Florida (Lynard et al. 1980): A cypress stand wetland on the University of Central Florida campus presently receives runoff from a 9.8 hectare basin, 67 percent of which is impervious. Water flow within the wetland is slow, allowing rapid sedimentation. The wetland was found to remove 95% of total nitrogen, 97% of total phosphorus, 99% of suspended solids, and 89% of BOD entering the wetlands. Environmental impacts to the wetland were not reported.

3. Brackish marsh, Palo Alto, CA. (Chan et al. 1981): A 240 acre brackish marsh in a Palo Alto flood control basin has received that city's stormwater runoff for over twenty years. Basin drainage area is 13,887 acres. Removal rates were observed for BOD (54%), solids (87%), volatile suspended solids (85%) and total nitrogen (37%). The marsh was a net source of phosphorus. Sedimentation and filtration accumulated pollutants in sediments in the upper reaches of the basin. Concentrations of copper, cadmium, lead and zinc in the flood basin freshwater and saltwater plants appeared to be comparable to control areas not receiving runoff. Monitoring by the Association of Bay Area Governments (ABAG) has revealed no indication of bioaccumulation of heavy metals in the vegetation or benthic invertebrates (Burstynsky 1986, pers. com.). Significant accumulations of lead were found in the crustacean Corophium, which is noted for its ability to store the metal in an inert crystal form.

4. High altitude meadow, Lake Tahoe, CA. Morris et al. (1981) investigated the use of a high altitude natural meadowlands and marsh to treat suface runoff entering Lake Tahoe. Contributing watershed consists of a mix of urban, rural residential, pasture and forested lands. Several sites were investigated. Sheet flow conditions were found to greatly enhance removal of suspended solids (up to 99%), phosphorus (93%), and nitrogen (67%), whereas water quality improvements were not observed in areas where stormwater flow was channelized. Nutrient removal approached that of conventional tertiary treatment.

5. Vegetated retention basin, Montgomery County, Maryland (Lynard et al. 1980): A 2.4 hectare constructed permanent pool with 45,600 m3 dead storage (37.1 acre feet) and vegetation lining the edge of the pond, removed 99% of total phosphorus, 97% of BOD, 99% of nitrogen, 96% of iron and lead, and 98% of cadmium and zinc. Stormwater was detained for 22 hours at peak inflow rates of 0.62 m3/s. A key factor cited for the high removal rates was the large permanent volume of the pond which allowed for sedimentation.

6. In a detention pond-wetland system, Orlando, Fla., Martin (n.d.) studied the effectiveness of a detention pond-wetland system in central Florida in reducing lead in urban stormwater. Stormwater is channelled first into the detention pond and then into the wetland. The pond (9,000 square feet, 8 feet deep) and wetland (34,000 square feet, 0-2 feet deep) together retained an average of 72% of the total lead that was introduced. The wetland vegetation included cypress, bay, maple and willow trees; wax myrtle, willow and Brazilian pepper bushes; and small cattail, duckweed, lillies, algae, moss, briars and broomsedge plants. During storm events, water was observed to short-circuit in the detention pond and flow directly from the inlet to the outlet. This was not observed in the wetland, where shallow depths and thick vegetation effectively prevented short-circuiting during storms. Four of the 12 storms monitored showed an increase in the total lead load leaving the detention

pond, and was attributed to scouring and resuspension of sediments in the pond. The wetlands, however, consistently reduced the amount of lead being transported by the runoff, with a mean reduction of 75 percent. This greater efficiency (compared to the pond) was attributed to the wetlands greater area, longer detention time and thick vegetation.

7. Palustrine/Lacustrine wetlands, Minneapolis- St. Paul Metropolitan area, Minnesota (Brown 1985): Four lake watersheds were selected to analyze the effects of wetlands on sediment and nutrient input to lakes from urban runoff.

Fish lake wetland (6.4 hectare) has an artificial impoundment which was found to increase the settling of suspended solids. Five percent of the wetland is open water, with no defined channels, and a mean water depth of 1.2 meters. Decrease in nutrients of the discharged water was attributed to uptake by a dense stand of cattails, which covered 80 percent of wetland.

Spring Lake wetland is a 26 hectare constructed wetland which was designed as a runoff sedimentation area. This wetland is primarily open water, with a water depth of 1.3 meters. The watershed consists of 61 percent agriculture, 20 percent lakes and wetlands, 15 percent grasslands and forest, and 4 percent residential. The site was found to be ineffective in decreasing sediment or nutrient concentrations. Its small storage capacity was found to allow frequent flushing of accumulated sediments. The outflow during peak flows contained sediment concentrations as much as 22 times greater than the inflow.

The two other wetlands studied yielded unreliable information due to runoff inputs that could not be accounted for or measured properly.

Brown (1985) concluded that three characteristics of a wetland that are most effective in decreasing suspended solids and nutrients are 1) an impoundment or detention to increase sedimentation; 2) an undefined channel flow that disperses incoming sediments, and 3) dense vegetation growth throughout wetland to reduce flow velocity and wave action.

8. A 50 acre seasonal freshwater artificial wetland is being created in Freemont, CA. for stormwater treatment and provision of wildlife habitat (Chan et al. 1981). Constructed in 1982-83 and still in the process of being vegetated, the wetland will serve as an experimental facility for examining the effectiveness of wetland treatment, providing valuable management information for the future. The wetland will become heavily vegetated with cattails (<u>Typha latifolia</u>) which are known to take up significant amounts of pollutants. Macrophytes such as pondweed and algae will become established in an open water pond which will act as a settling basin. A comprehensive monitoring program began in 1983. The wetland has an upstream sediment trap which will act as a contingency in case of an accidental spill

(such as gasoline), as well as to intercept heavy loads of sediments expected from new construction in the watershed. In newly developing areas of the Bay Area, construction-related erosion causes up to 15 to 20 times as mush soil loss as background conditions.

**Pollutant removal processes should be comparable between wastewater and stormwater treatment systems.** Stormwater generally has lower levels of nutrients, similar levels of heavy metals and BOD, and more suspended sediments than secondary-treated wastewater (Silverman 1983). Stormwater also has larger, more mineral-type particles where sewage effluent from treatment plants has smaller particles of lower density with higher organic content (Duxbury, 1986). Synthetic organics and oil and grease in stormwater vary widely and are dependent on land use patterns in the watershed. Nevertheless, some researchers feel that the characteristics of wastewater and urban runoff are similar enough that findings in the wastewater literature may be analogous to stormwater systems.

**Control of the "first flush" from a storm is not an effective management tool in Western Washington where rainfall is frequent and light** (Canning 1985). Contrary to findings in other regions of the country, in Western Washington the greatest amount of pollutants generally do not come off during the first part of a storm (Farris 1979). Areas where rainfall is infrequent, such as eastern Washington, can receive 90 percent of a pollutant load in the first surge of a storm. First flush effect may occur in Western Washington after the dry spell in the summer. Effective nonpoint source control strategies in Western Washington should address all runoff quantities, not just the first flush.

Research by Galvin et at. (1982) in the Seattle Metropolitan Area sampled for priority pollutants in stormwater. Results indicated that many of the priority pollutants in runoff originated from motor vehicles and were associated with fine particulates on street surfaces. Not surprisingly, Farris et al. (1979) found a close relationship between total amount of pollutants in stormwater and land use in the drainage basins of the Seattle Metropolitan Area. The greatest quantity of pollutants were contributed by industrial sites, followed by significantly lower concentrations in commercial sites and residential areas.

Research on the use of grassed drainage swales and ditches for water quality control shows favorable results. The Washington Department of Transportation found that a grassy swale of at least 200 feet in length can remove approximately 80 percent of suspended solids, COD, and total recoverable lead (Canning 1985).

In the National Urban Runoff Program Bellevue study site, street sweeping was not found to be an effective management tool for reducing nonpoint pollution. Smaller particulates which carry the heaviest pollutant load remained on the road surfaces after sweeping and continued to be a major contribution to urban runoff (Pitt and Bissonnette 1984).

**Wetlands can be "managed" and artificial wetlands can be created to improve water quality.** (Chan 1981, Canning 1983, EPA 1985).

Some basic design principles for artificial wetlands for urban runoff water quality improvements were summarized by Canning (1985):

A. Dense growing plant species should be planted. These include bulrush (Scirpus validus), common reed (Phragmites communis), and common cattail (Typha latifolia).

B. Water should move through a wetland as sheet flow, with no open water or open channels.

C. Constant water levels should be maintained in wetland over long periods of time to promote vegetative growth.

D. Sedimentation should occur in a detention/retention basin or surge basin upstream from wetland. The wetland should not be used for sedimentation. This will remove substantial amounts of pollutants from the water before it enters the wetland.

E. Discharge to a wetland should be by distributary channels to promote sheet flow, versus discharging through a single inlet.

F. Wetland vegetation may be harvested to prevent nutrient and heavy metal build up. In Europe, reeds are harvested annually, and rushes every 2 to 3 years, and are used for wicker furniture.

These design principles can be utilized for the selection and management of potential natural sites for water quality and stormwater management studies.

## III. WHAT WE DO NOT KNOW

**It is uncertain what the long term consequences are of routing urban stormwater through wetlands.** Long term consequences of using wetlands for wastewater treatment are also unknown.

Several authors have raised warning flags regarding the discharge of stormwater to wetlands:

"Long and short-term impacts of retention of sediments and nutrients in the wetland on flora and fauna is unknown. Detailed studies of mineral cycling in wetlands are needed to evaluate all the effects on water quality as well as the effects on the wetland flora and fauna if wetlands are to be used as areas for reducing sediment and nutrient loads in runoff." Brown 1985

"Special precautions should be taken with the use of natural wetlands for stormwater control, particularly those with high wildlife habitat values." Canning 1985

"The interaction of numerous plant and animal species on pollution removal in a wetland is not well understood. Management of wetland vegetation to optimize pollutant removal requires further investigation." Chan 1981

"Insufficient data exist for long-term exposure of receiving waters to pollutants." Galvin 1982

"Little is known of the pollutant removal effectiveness of wetlands treating urban stormwater runoff, although the potential is high.... care must be taken to monitor stormwater wetland treatment systems to learn the environmental fate of pollutants." Silverman 1983

**It is uncertain how changes in detention time and water levels will affect wetlands.**

The depth of water in a wetland is closely associated with the water regime of the wetland. Marked changes in water depth can result in plant species shifts and affect reproduction, as well as influence dissolved oxygen levels and many processes related to dissolved oxygen concentrations (EPA 1985).

Teskey and Hinkley (1977) assessed the plant and soil responses in woody riparian and wetland communities to both natural and managed water level changes. The authors focused on water level changes related to flood control activities in flood plain regions. Unfortunately, their work does not address hydrological impacts associated with short-term (24-36 hour) impoundments of stormwater in wetlands. The authors focus primarily on woody riparian vegetation. Flooding responses were considered on a scale of flooding from two weeks to several years. The major effect of flooding is the creation of an anaerobic soil environment which can affect normal root functions. Response of individual species depends on the tolerance to submersion, flooding and soil saturation. Water logged soils can become anaerobic (reduced) within three days. The availability of nutrients in soils varies according to the oxidation-reduction (redox) potential of the soil. The redox potential decreases as it becomes water logged and oxygen levels drop. In most aerated soils the redox potential is between +400 and +700 millivolts (mv), while in waterlogged soils the potential ranges from -300mv when reduced to +700 when oxidized (Chapman, 1982).

In a subsequent volume, Walters et al. (1980) assessed the flood (and drought) tolerance of woody plants in the Pacific Northwest and Rocky Mountain regions. This paper may provide information on the potential response and tolerance of woody plants living on the upland fringe of wetlands that receive intermittent flooding.

Davis (1980) assessed the response of submerged vascular plant communities (pondweeds, watermilfoil, naiads, wild celery, etc.) to environmental change. Factors considered included light transmission, fluctuating water levels, wave action, sedimentation, nutrients, and seasonal effects. His conclusions are too general for purposes of this study, but does warn about the need to assess cummulative impacts associated with hydrologic and/or environmental changes.

**It is uncertain what impacts nonpoint toxicants in stormwater will have on groundwater.**

Groundwater interactions can be difficult and costly to investigate. Some authors (Carter et al. 1978, Adamus and Stockwell 1983) feel that wetlands may not play significant roles in recharging groundwater. In fact, wetlands may act more often as groundwater surface discharge areas (PSWQA 1986). Many wetland types, such as swamps, wet meadows and riverine-related systems are fed by groundwater at or near the surface for some parts of the year (Reppert et al. 1979). During drier months, however, these same wetlands can act as groundwater recharge zones. Most permanent wetlands cannot be considered to be prime groundwater recharge areas (Reppert et al. 1979).

**It is uncertain if nonpoint toxicants in stormwater will be bioaccumulated in wetlands.**

> "The potential for bioaccumulation of heavy metals from urban runoff to levels detrimental to wildlife has not been examined" (Silverman 1983).

However, an EPA study that looked into the ecological consequences of applying secondary-treated wastewater to land concluded that such practice would not result in significant accumulation of metals in the soils (Silverman 1983). Since heavy metal levels in stormwater are not necessarily higher than they are in wastewater, Silverman (1983) argues that accumulation in the soils may not be anticipated. Bioaccumulation is a process that occurs in the biota, and may occur in wildlife even though the soils do not magnify the toxic concentrations (Duxbury, 1986). This is an area of needed research.

**The public health risks of storing stormwater in wetlands are uncertain.**

Silverman (1983) states that there is insufficient information on the removal of pathogenic microorganisms through wetlands treatment. Bacteria and viruses from wastewater applied on land have been found to survive for extended periods of time in both soil and groundwater (Silverman 1983). Bacteria do not survive longer than a few days in natural waters, and begin to die off. Viruses survive for longer periods (Canning 1985). The removal efficiency of pathogenic microorganisms through wetlands treatment of stormwater is not known. Research needs to be done on the public health risks of stormwater storage in wetlands.

It has not been established that coliforms can be used as indicators for human pathogens in stormwater (DeGroot 1982). Coliforms can originate from a variety of sources (pets, hobby farms, wildlife, human) and their accuracy as indicators for pathogens depends on their source.

**The impacts to systems downstream from wetlands is uncertain.**

Many water bodies downstream from wetlands depend on nutrient regulation and other water quality improvements by the wetland to maintain a balanced ecosystem, and it is uncertain how they will be affected by management activities upstream.

## IV. CONCLUSIONS

There is a limited amount of information in the literature regarding the long term effects of using freshwater wetlands for stormwater storage and nonpoint pollution control. Much of the related literature pertains to the use of wetlands for sewage effluent treatment. Some work has been done in other parts of the country utilizing natural or artificial wetland for flood control and/or water quality management. Water quality improvements from these studies show promise, but their direct application to this region is limited. Some researchers believe the characteristics of wastewater and urban runoff are similar enough that findings in the wastewater literature may be analogous to stormwater systems. These findings can be confirmed by careful studies in the Northwest to help fill the gaps in present knowledge.

It is well established in the literature that wetlands improve water quality. The long term consequences of storing urban stormwater in wetlands is uncertain and is an area of needed research. Information is needed before rational management and policy decisions can be made. Few stormwater and wastewater treatment studies have operated long enough to examine long-term impacts to wetlands. The wastewater literature has revealed that in certain cases, wastewater addition to wetlands has resulted in significant ecosystem changes such as simplification of communities and elimination of some species, functions and values. On the other hand, some wastewater application systems have revealed no negative effects. Wetland classes vary widely in their ability to improve water quality and their tolerance to wastewater or stormwater pollutants. This indicates the need to conduct site specific studies before management decisions are made.

**Certain principles for water quality improvements can be summarized from the literature:**

1. Sedimentation is a major mechanism in water quality improvement. Sedimentation can occur in a flood control detention/retention basin, over grassy swales, and in wetlands.

2. Longer detention times (20-36 hours) improve water quality more than shorter detention times. This is due to increased sedimentation, contact time with substrate, absorbtion, and other factors.

3. Traditional detention times for flood control of 1-12 hours may be too short to substantially improve water quality.

4. The size of wetland is important. A site which is too small or has a rapid flushing rate may result in resuspension of sediments and net export of particulates, nutrients, and toxicants.

5. Sheet flow is preferred over channel flow for water quality improvements.

6. Dense vegetative growth throughout the wetland reduces flow velocity increasing sedimentation and water quality improvement.

7. Sedimentation ponds to intercept heavy sediment load from upstream construction activities and accidental spills are advisable.

8. Controlling the "first flush" of stormwater is not an effective management tool in Western Washington.

It should be kept in mind that wetlands are not final sinks for nutrients, heavy metals and other substances that are discharged to them. Wetlands transform, remove, store, and release those substances, at modified rates and times.

There are many uncertainties regarding the long term consequences of using freshwater wetlands for urban stormwater management:

1. The hydrological impacts associated with changes in detention time and water levels are uncertain.

2. The risks of contaminating groundwater with toxicants or pathogens in stormwater are unknown, as are the recharge /discharge characteristics of most wetlands.

3. It is uncertain if nonpoint toxicants in stormwater will bioaccumulate in the biota, or will accumulate in the soils.

4. Public health risks of exposure to pathogenic microorganisms in stormwater are unknown.

5. The impacts to systems downstream from wetlands that depend on normal wetland functions are unknown.

> Sloey et al. 1978 noted ... "In the past, we caused the deterioration of the quality of our surface waters by using them to treat our wastes. When the practice was initiated, we marvelled at the remarkable ability of water to "self-purify." We based our decisions on short-term observations and immediate economics. Years later, the results of long-term overloading became evident. Lest we make the same mistake in handling our valuable and diminishing wetlands, it is mandatory that we carry out long-term, carefully monitored experiments at a severely limited number of sites. It is also important that those conducting the experiments document changes very carefully in the natural system that could signal future problems."

Sloey was referring to the use of wetlands for wastewater treatment but his caution deserves consideration when evaluating the active use of wetlands for stormwater management.

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